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DESIGNATED/ELECTED OFFICE (DO/EO/US)

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INTERNATIONAL APPLICATION NO.

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PRIORITY DATE CLAIMED

23 December 1997 (23.12.97)

TITLE OF INVENTION

LOW NOISE ENCODING AND DECODING METHOD

APPLICANT(S) FOR DO/EO/US

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Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
 - a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
 - b. ☒ has been transmitted by the International Bureau.
 - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ A copy of the International Search Report (PCT/ISA/210).
8. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
 - a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
 - b. ☐ have been transmitted by the International Bureau.
 - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
 - d. ☒ have not been made and will not be made.
9. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
10. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
11. ☒ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).

Items 13 to 20 below concern document(s) or information included:

13. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98 with references attached
14. ☒ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☒ A **FIRST** preliminary amendment.
16. ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
17. ☐ A substitute specification.
18. ☐ A change of power of attorney and/or address letter.
19. ☐ Certificate of Mailing by Express Mail
20. Other items: Copy of PCT/IB/306-Notification of Change

EL498033911US

CERTIFICATE OF MAILING UNDER 37 CFR 1.10

May 31, 2000

"Express Mail" mailing no.

Date of Deposit

I hereby certify that this application is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 on the date indicated above and is addressed to the Assistant Commissioner for Patents, Washington, D.C. 20231.

David Fornarotto

Typed or printed name of person
mailing application

David Fornarotto
Signature of person mailing
application

09/555488

21. The following fees are submitted:

BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) :

- ☐ Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO \$970.00
- ☒ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO \$840.00
- ☐ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO \$690.00
- ☐ International preliminary examination fee paid to USPTO (37 CFR 1.482) but all claims did not satisfy provisions of PCT Article 33(1)-(4) \$670.00
- ☐ International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(1)-(4) \$96.00

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840.00

Surcharge of \$130.00 for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (e)).

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE
Total claims	30 - 20 =	10	x \$18.00
Independent claims	6 - 3 =	3	x \$78.00

180.00

234.00

Multiple Dependent Claims (check if applicable). ☐**TOTAL OF ABOVE CALCULATIONS =**

1254.00

Reduction of 1/2 for filing by small entity, if applicable. Verified Small Entity Statement must also be filed (Note 37 CFR 1.9, 1.27, 1.28) (check if applicable). ☐**SUBTOTAL =**

1254.00

Processing fee of \$130.00 for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (f)).**TOTAL NATIONAL FEE =**

1254.00

Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) (check if applicable). ☒**TOTAL FEES ENCLOSED =**

40.00

1294.00

Amount to be:
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☐ A check in the amount of _____ to cover the above fees is enclosed.☒ Please charge my Deposit Account No. 07-0832 in the amount of 1294.00 to cover the above fees.
A duplicate copy of this sheet is enclosed.☒ The Commissioner is hereby authorized to charge any fees which may be required, or credit any overpayment to Deposit Account No. 07-0832 A duplicate copy of this sheet is enclosed.**NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.**

SEND ALL CORRESPONDENCE TO:

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26,932

REGISTRATION NUMBER

May 31, 2000

DATE

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant : Haoping Yu; David Lowell McNeely, 416 Rec'd PCT/PTO 31 MAY 2000
Billy Wesley Beyers Jr.

Filed : Herewith

For : LOW NOISE ENCODING AND DECODING METHOD

PRELIMINARY AMENDMENT

Hon. Commissioner of Patents and Trademarks
Washington, D.C. 20231

Sir:

In the US national phase application of PCT/US97/23992 filed
herewith, please enter the following amendments.

IN THE ABSTRACT:


Please add the attached amended Abstract.

REMARKS

To meet the requirements of the United States, the Abstract (as
originally filed in the PCT application) is added. Reference indicia has been
removed. No new matter has been added.

No fee is believed to have been incurred by virtue of this
amendment. However if a fee is incurred on the basis of this amendment, please
charge such fee against deposit account 07-0832

Respectfully submitted,
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May 30, 2000

ABSTRACT

An adaptive digital image processor precedes an MPEG2 encoder. The
5 processor receives a high definition video signal intended for broadcast or
storage, and adaptively low-pass filters the signal. The signal is subjected to
low-pass two-dimensional filtering to eliminate encoding artifacts and related
noise. The video signal is then horizontally down-sampled to create a lower
resolution hybrid signal. A receiver decodes and decompresses the hybrid signal.
10 The hybrid signal is upsampled to its original resolution using existing hardware
and software with a software modification.

LOW NOISE ENCODING AND DECODING METHOD

Field of the Invention

This invention concerns image compression for reducing the bandwidth requirements of a digital video encoder.

Background of the Invention

The United States Federal Communications Commission (FCC) has approved a digital high definition television (HDTV) standard proposed by the Grand Alliance (GA), clearing the way for terrestrial digital television broadcasting in the United States. The GA HDTV system adopted the Motion Pictures Expert Group (MPEG2) video compression standard. For details, see "Information Technology - Generic Coding of Moving Picture and Associated Audio Information: Video," ISO/IEC 13818-2: 1996(E). Utilizing modern and sophisticated video compression methods, such as source processing, motion estimation and compensation, transform representation and statistical coding, an MPEG compression system can reduce the transmission bit rate by a factor of 50 or more. A full HD signal for one second requires approximately one billion bits before compression. As proposed in the GA specification, 1920 by 1080 pixel (picture element) images at a rate of 60 field per second are compressed to 18 megabits per second for digital broadcast.

The GA video compression system normally comprises two major subsystems, a pre-processor and an MPEG2 video encoder, followed by an output buffer. The input to the pre-processor is analog video in RGB format. The pre-processor digitizes the input signals and performs gamma correction on each color component to compensate for the non-linear response of the imaging camera. Gamma correction reduces the visibility of quantization noise contained in the compressed image, especially in the dark regions of the image. Then the pre-processor linearly transforms the digitized and gamma corrected RGB samples to the SMPTE 240M YC1C2 color space. Finally, the resulting chrominance components are sub-sampled to form the 4:2:0 digital video input signal. In addition to the tasks just described, the pre-processor may perform image conversion. For example, in a broadcast digital satellite system, the video signal is horizontally decimated from 720 pixels per line to 544 pixels per line to further reduce bandwidth requirements. This signal is sent to the MPEG2 video encoder.

The MPEG2 video encoder compresses the input digital video signal by removing some of the temporal redundancy between frames and some of the spatial redundancy within frames. Generally, compression is achieved by utilizing a number of different techniques in succession as described above. Adjusting the quantization precision allows the encoder to generate the compressed bit stream at any rate specified by the application. The quantization in MPEG2 systems is performed on the DCT coefficients of a data block, which may be the original image information or residual information from motion estimation. Using quantization matrices in combination with scalable quantization step sizes, the quantizer selects and quantizes only a small fraction of the DCT coefficients from every DCT block for transmission, resulting in significant data reduction. The quantization matrices can be varied on a frame basis according to the statistical distribution of the DCT coefficients and the content of the video signal. For different areas within a frame, the quantization can be fine tuned on a macroblock by macroblock basis by scaling the quantization step size based on the complexity of the macroblock. For a given output bit rate, an output buffer will provide control signals used by the encoder to adjust the quantization step size for a particular frame to maximize quantization resolution within the available bandwidth.

Ideally, the video compression system removes high frequency components which will not be perceived as missing by viewers when the image is reconstructed and displayed. The remaining low frequency components are quantized to fit within the available bandwidth. Quantization noise introduced to the signal should also be invisible to viewers upon image reconstruction. However, in a real system a trade-off is made between the information to transmit and the quantization step size for an available bandwidth. If the system does not drop sufficient coefficients for quantization, the system increases the quantization step size resulting in blocky artifacts in the reconstructed image. If the picture loses too much high frequency information during the compression process, the reconstructed image will contain other noticeable edge artifacts.

Moreover, differences in quantization between each frame causes frames within a group of pictures (GOP) to contain varying high frequency components. An I frame, for example, may have a substantial amount of high frequency coefficients dropped during encoding, whereas P and B frames retain high frequency components corresponding to those dropped in the I frame. The reconstructed GOP will now contain artifacts because the high frequency information varies between frames used to reconstruct each other.

These problems occur within the GA system as currently defined. Compressing the HD image signal further only decreases displayed picture quality. Satellite broadcast providers are unwilling to transmit HD signals because only one program can be transmitted at a time in a transponder. To date, compressing an HD program sufficiently to fit two programs in one satellite channel (for example, 24 MHz 4-PSK Modulation) at the same time results in unacceptable viewer picture quality. Therefore, satellite broadcast providers are hesitant to broadcast HDTV due to inefficient use of the channel. Likewise, terrestrial broadcast providers

are reluctant to commit to providing full HD programs when one program fully occupies a channel in which several SD programs can reside.

Summary of the Invention

In accordance with the principles of the present invention, a digital image processor identifies a video signal type, and selectively converts the original signal format to a different format as necessary. The converted signal is filtered and reconverted to the original format as necessary. The filtered signal is converted to a lower resolution and compressed to a target bit rate. Finally, the compressed signal is conveyed to an output data channel.

Brief Description of the Drawings

Figure 1 shows one configuration for a video compressor in accordance with the present invention.

Figure 2 shows detail of unit 22 from Figure 1.

Figure 3 shows one possible response of an adaptive filter included in unit 22.

Figure 4 is a flow chart of an exemplary transmitting system using the present invention.

Figure 5 is a flow chart of an exemplary receiving system using the present invention.

Description of the Preferred Embodiment

An MPEG2 encoder including apparatus according to the principles of the present invention includes a two dimensional (vertical and horizontal, for example) filter prior to the encoder. The encoder, the output buffer and the filter each produce information which may be utilized by the other units to improve overall efficiency. Such information concerns image motion, image contrast, quantization matrix selection, scale factor selection, bit rate out of each unit, image texture, for example. The information is communicated between the units by a controller which oversees the encoding process, or by individual controllers resident in each unit.

The controller evaluates the incoming information and identifies commonalities over a group of pictures, a frame, or a partial frame which can be advantageously used to modify the operation of the filter and/or the encoder to efficiently encode the group, frame or partial frame

5 to the target bit rate. Generally, the filter is adjusted because adjusting the filter induces less noise than adjusting the encoder. Also, the filter is actually a set of filters which allows the greatest flexibility by adjusting individual filter coefficients as needed. These filters are a horizontal anti-aliasing low-pass filter, a vertical low-pass filter, and a two-dimensional low-pass filter, generally in the sequential order just
10 given. The controller evaluates the received information against current filter and encoder setup, and makes adjustments to one or more filters and/or to the encoder according to one or more predominant commonalities. The end result is that the input signal is low-pass filtered by the filter in a manner which generally allows the encoder to encode the image uniformly across a group of pictures, a frame, or a partial frame
15 relative to a dominant commonality of the data being uniformly encoded.

The encoded signal may be transmitted in the available bandwidth, and then reconstructed and displayed without artifacts which would have been present otherwise. For high definition signals having 1920 by 1080 pixels per image frame, the horizontal resolution is reduced to 1280 pixels per line after filtering and before
20 encoding to further reduce the bandwidth of the transmitted signal. The result is a hybrid image resolution which HD receivers can receive, decode and display with a minor software change.

An exemplary configuration of the video compression system according to the present invention is shown in Figure 1. An input video signal is received by movie
25 detector 20, which identifies if the signal is a movie (film) signal which has been reformatted by telecine methods from 24 frames per second to 30 frames per second. The reformatted movie signal is directed to the appropriate section of adaptive image processor 22 as will be described. If the input signal is not a reformatted movie signal, the signal passes to another section of adaptive image processor 22.
30 Identification of telecine movie signals occurs by known methods.

Processor 22 receives control information from output buffer 26 and from MPEG2 encoder 24 via controller 28, and filters image frames so that the encoder 24 can efficiently encode the frame to be within the available bit rate, and to be generally free of noticeable artifacts. Processor 22 filters the signal in two dimensions (2-D)
35 (for example, horizontal and vertical) as needed to improve the reconstructed image quality of a MPEG2 encoded bit stream constrained to an average bit rate. The goal is to modify local 2-D frequency content of the source to improve MPEG2 coding efficiency in a manner least injurious to the MPEG2 reconstructed image with regard to image sharpness and encoding artifacts. Filtering of the signal can be done on

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5 predetermined data, for example, a group of pictures (GOP) or frames, a single frame, or pixel by pixel.

The 2-D filter low-pass filters the image. Optimally, the high frequency information which is removed is either redundant or not noticeable to the viewer. In practice, to attain the desired bit rate, some high frequency information may be
10 removed which is noticeable to a viewer. However, a system which includes a processor 22 before MPEG2 encoding generates an image which is superior to a system without a processor 22, as will be discussed.

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The filtered signal is encoded by MPEG2 encoder 24, which receives image parameters from processor 22 and output buffer 26 via controller 28, and adjusts MPEG2 compression to comply with available bit rate. Compression occurs in the same manner as described in the GA specification. Encoder 24 sends the compressed data to output buffer 26. Buffer 26 provides the compressed data at a predetermined rate to be transport encoded, modulated, and transmitted via a transmission channel using known signal processing techniques. Prior to modulation, the compressed signal may be sent to a statistical multiplexer to be multiplexed with multiple programs for transmission on a single channel. Signal processing units after buffer 26 are well known and therefore are not shown in Figure 1 to simplify the drawing.

The video compression system can be configured to accept any type of video signal. The system of Figure 1 is configured to accept both television (camera) and movie (film) programs formatted to known industrial standards. One common configuration would be for the system of Figure 1 to receive the output from a pre-processor as previously described in the background, for example. The system may be configured to accept other types of video signals by adding appropriate hardware and/or software. These configurations are not shown to simplify Figure 1.

Movie detector 20 recognizes the presence of certain relationships in the input signal that can be used to improve coding efficiency: (Type 1) 60 Field/Second Interlaced Scanned Source, (Type 2) 60 Field/Second Interlaced Scanned 30 Frame/Second Movie, (Type 3) 60 Field/Second Interlaced Scanned 24 Frame/Second Movie, (Type 4) Progressive Scanned Source, (Type 5) 60 Frame/Second Progressive Scanned 30 Frame/Second Movie, and (Type 6) 60 Frame/Second Progressive Scanned 24 Frame/Second Movie. Detection occurs in response to an external control signal (not shown) or by known techniques such as those used in current standard definition (SD) MPEG2 encoders. Signal format information is passed with the signal to adaptive image processor 22, as is described below. Movie detector 20 also detects whether the signal is interlaced scan or progressive scan type and passes that information to processor 22. These scan types are exemplary and define parameters by which signals are directed through processor 22. Implementations for other field and frame rates may also be used.

Adaptive image processor 22 performs several programmable functions which reduce the amount of data to be compressed by encoder 24. Processor 22 operates on each frame, in general, so that the processed frame can be optimally encoded to eliminate or greatly reduce noise which is noticeable to the viewer. Processor 22 may generally be viewed as a spatial varying 2-D low-pass filter, because it down-samples each image frame spatially and adaptively filters selected 2-D high frequency components from the signal. The adaptive filtering can be adjusted over a series of frames, for a single frame, or pixel-by-pixel to produce a processed frame.

Processor 22 can facilitate encoding for any type of signal. However, for this embodiment, processor 22 is programmed to operated on HD data as defined by the GA specification. This can be either 1920 by 1080 pixels per image or 1280 by 720 pixels per

image. According to the GA specification, each HD format requires approximately 18 megabits per second for broadcast. To simplify the discussion, only the 1920 by 1080 format will be discussed in detail. The discussion is equally applicable for the 1280 by 720 format or any other format.

5 Figure 2 shows details of adaptive image processor 22. Depending on signal format information received from detector 20, the image signal is routed by controller 28 (Figure 1) to an interlaced to progressive converter 221 (Type 1), a de-telecine unit 222 (Type 2,3), or passed through unmodified (Type 4-6) to a spatial band-limit, low-pass filter 223. Filter 223 receives the output of units 221 and 222 after these units have processed the signal.

10 Converter 221 receives the signal if its format contains 60 Hz interlaced fields and converts the signal to progressive frames at the rate of 60 frames per second. A progressive frame includes all the image information in each frame. Filtering a progressive scan signal typically does not introduce artifacts such as may occur when filtering field information of an interlaced signal. Converter 221 utilizes known methods to convert interlaced fields to a
15 progressive frame.

De-telecine unit 222 eliminates the redundant fields of a 60 Hz interlaced scanned movie and reconstructs the original progressive scanned movie. The progressive format allows subsequent vertical low-pass filtering to be free of motion artifacts. If a movie source (type 2 or type 3) input were processed as a type 1 source, vertical low-pass filtering would degrade
20 the ability of the MPEG2 encoder to detect and properly process movie source material. Coding efficiency would suffer. Unit 222 converts the signal to a progressive format and removes the redundant fields/frames before filtering because filtering may filter the redundant information differently. If the redundant information is not removed before filtering the
information may not be identical after filtering, and the encoder may not recognize the signal as
25 a Type 2/3 signal. Then the encoder would encode information which otherwise would have been removed due to the redundancy.

Also, the design of processor 22 is simplified by providing a single output clock from unit 222. If unit 222 provides output progressive film images at a rate of 24 frames per second and 30 frames per second, two output clocks and supporting circuitry would be required.

30 Signals which were originally generated in a 30 frames per second progressive format pass directly to filter 223. Filter 223 expects video information represented as complete image frames. Spatial, low-pass filter 223 is actually a set of filters. For example, the first filter is an anti-aliasing, horizontal low-pass filter. The second filter is a vertical low-pass filter. The final filter is a 2-D low-pass filter as previously described. The coefficients of each filter tap may
35 be adaptively set according to control information from encoder 24 and buffer 26 as seen in Figure 1. The progressive signal is low-pass filtered horizontally to eliminate aliasing from subsequent down sampling in sample rate converter 226. The final horizontal output of the 1920 pixels per line will be 1280 pixels per line, as will be discussed. To eliminate alias noise within the final signal, low-pass filter 223 has a cut off frequency of 640 cycles per line. The

horizontal anti-alias filter included in unit 223 may be a 17 tap finite impulse response (FIR) filter with the following tap coefficients:

$$[f_0, f_1, \dots, f_{15}, f_{16}] = [-4, 10, 0, -30, 48, 0, -128, 276, 680, 276, -128, 0, 48, -30, 0, 10, -4]/1024.$$

Encoding HD video signals at a reduced bit rate normally requires additional vertical low-pass filtering to further reduce the bandwidth of the video signals. Removing vertical high frequency energy before MPEG encoding is necessary to achieve acceptable overall picture quality. Vertical frequency regions of highest phase sensitivity are attenuated. The vertical cut off frequency is set to some fraction of the Nyquist frequency. For example, a cut off frequency equal to approximately half the line rate of the HD input signal may be appropriate for some video material. For an HD signal with 1080 lines/picture height (l/ph), this would correspond to a cut off of 540 l/ph. This frequency may be programmable, and a programmable cut off frequency would be determined by controller 28 from parameters available from encoder 24 and buffer 26 of Figure 1 (i.e. desired bit rate, quantization matrices, etc.). The vertical low-pass filter included in unit 223 may be a 17 tap FIR filter with the following tap coefficients.

$$[f_0, f_1, \dots, f_{15}, f_{16}] = [-4, -7, 14, 28, -27, -81, 37, 316, 472, 316, 37, -81, -27, 28, 14, -7, -4]/1024.$$

As an alternative, the cut off frequency may be equal to twice the line rate of an SD signal. Generally, the vertical low-pass filter follows the horizontal anti-alias filter.

Processor 22 performs vertical filtering rather than vertical decimation, thereby maintaining constant vertical line resolution. Currently, filtering is preferred over decimation for interlaced video signals. Converting vertical line resolution for an interlaced image sequence requires complex hardware and software, resulting in high receiver costs. Vertical sample rate conversion compromises vertical high frequency performance because of the increasing tap complexity combined with Nyquist sampling (i.e., no oversampling). Cost considerations at the receiver currently discourage reducing vertical resolution to reduce artifacts and the encoded bit rate. The displayed picture would be significantly degraded by employing the current technology in vertical sample rate converters in place of the vertical low-pass filter described above. However, efficient and cost effective vertical sample rate converters may replace the vertical filter described herein without departing from the principles of the present invention.

The coefficients for both the horizontal and vertical low-pass filters can be modified by software, and applied to the pixel level, if necessary, to attain the target bit rate without generating artifacts in the reconstructed image. Generally, coefficient modification on a frame basis is sufficient. An alternative for slower processors is to preprogram a number of different coefficient sets for the filters and select the most appropriate set for the image information

being processed. The greater flexibility of the adaptive filters enables the overall system to produce a data stream with fewer artifacts relative to a system without adaptive filters.

After the signal has been low-pass filtered in the horizontal and vertical directions by unit 223, controller 28 determines whether the signal can be uniformly encoded by encoder 24 on a frame basis without introducing significant quantization noise. If so the signal passes to either unit 224, 225 or 226 depending upon its format, as will be discussed. If, however, the encoding process is likely to introduce noise and/or artifacts into the signal, it is sent to a two dimensional low-pass filter in unit 223 for further adaptive filtering. Control parameters from processor 22, encoder 24, and output buffer 26 (Figure 1) allow controller 28 (or an individual unit controller in unit 223) to determine if further filtering is needed. Control parameters used to make this determination are, for example, measurements of motion and contrast, available quantization tables, encoding efficiency and the current target bit rate.

The 2-D filter in unit 223 reduces high frequency information from an image frame primarily along the diagonal, instead of the horizontal or vertical directions alone. The human eye is very sensitive to high frequency noise in the vertical and horizontal directions relative to the diagonal directions. Removing sufficient high frequency information diagonally to allow uniform quantization by encoder 24 generally results in a better quality signal with less observable noise. The diagonal filter, like all previous filtering, operates on an entire image frame and is programmable.

The diagonal filter may be compatible with the quantization matrices in the encoder. Quantization matrices often use diamond shaped matrices for I frame quantization. However, these matrices often induce noise because B and P frames use other types of quantization matrices which retain the high frequency components during the compression and motion compensation process which occurs in encoder 24. The filters of processor 22 remove high frequency information from each image frame before MPEG2 encoder 24 processes the data into I, P and B frames in a motion estimation network. Therefore, high frequency components are generally eliminated from the P and B frames as well as from I frames. On reconstruction, the image is generally free from artifacts created by MPEG2 encoding as known.

Referring to Figure 1, in practice, the controller 28 evaluates signal parameters, (e.g., motion, contrast, etc.) before filtering a given frame by processor 22, and determines the coefficient settings for all filters in unit 223, including diagonal filtering needed. During the filtering process of a given frame, controller 28 monitors signal parameters from processor 22, encoder 24 and buffer 26 and changes coefficients as necessary to maintain the target bit rate with minimal artifacts/noise. Each frame is filtered based upon the most recent signal parameters and is passed to encoder 24 for compression, and then to buffer 26 as subsequent information is input into filter 223.

If the signal originated as a 24 frame per second movie signal, the filtered signal is applied to 3:2 pull down unit 224. Unit 224 duplicates selected frames to provide a 30 frames

per second output signal. This occurs by known methods. Then the signal passes from unit 224 to horizontal down-sampling converter 226.

Field sub-sampling unit 225 converts progressive signals from filter 223 from progressive to interlaced scan format. This conversion is accomplished by known methods.

Without conversion back to interlaced format, the signal would contain twice the amount of data, because the progressive frame rate from unit 221 is 60 Hz. The interlaced signal is applied to converter 226.

Sample rate converter 226 receives progressive signals at 30 frames per second directly from filter 223. Also, units 224 and 225 provide signals to converter 226 as described above.

Converter 226 down samples HD signals to the transmission format selected. This format does not need to be a standard format. It may be any image ratio and frame size that is desired. A non-standard format will require receiver modification, however.

When converter 226 receives 1920 by 1080 GA HDTV signals, converter 226 down samples the horizontal information and outputs a hybrid pixel frame format of 1280 by 1080.

GA HDTV compatible receivers are capable of receiving image frames containing 1920 by 1080 pixels and 1280 by 720 pixels. Therefore, GA compatible receivers may be modified to support 1280 pixels horizontal resolution and 1080 pixels vertical resolution. Compatible receiver hardware upsamples 1280 horizontal pixels to 1920 horizontal pixels in conjunction with an increase in vertical resolution. However, GA compliant receivers are not required nor programmed to receive an image frame resolution of 1280 by 1080 pixels (horizontal by vertical) as a defined format. The hardware is in place to receive and decode this resolution, but the supporting software to decode and to increase only horizontal resolution must be added. Adding the software is simple and inexpensive relative to redesigning and adding new hardware needed for other non-standard formats.

Processor 22 provides the hybrid 1280 by 1080 format because current display technology is incapable of displaying 1920 pixels/line resolution. Currently, the best television monitors can only display resolution to approximately 1200 to 1300 pixels/line. Therefore, limiting the output resolution to 1280 pixels/line in the horizontal direction has little if any adverse effect on picture quality. By providing a display resolution (1280 by 1080) which is supported by existing decoding and decompressing receiver hardware, receiver manufacturers will be minimally impacted because only a software change is necessary. For certain receivers, such as for broadcast satellites, the software modification can be downloaded and installed remotely via a satellite link. For these receivers there is no need for a service technician to become involved.

The hybrid format is advantageous because terrestrial and satellite program providers have been unwilling to transmit HD programs. A satellite transponder transmits a data stream of approximately 24 Mbits per second (Mbps). A terrestrial HDTV broadcasts can transmit up to 19 Mbps including the HD program at 18 Mbps and other information (such as audio, program guide, conditional access, etc.). Present satellite transponders can each carry at most

one HDTV program, which satellite program providers contend is not sufficiently profitable. Simply reducing the horizontal frame resolution from 1920 to 1280 is not sufficient to allow the simultaneous transmission of two HD programs on a single satellite transponder. The filtering provided by processor 22 advantageously permits such dual HD transmission on a single channel.

The filtering characteristic provided by processor 22 may have various shapes, including diamond, cross, and hyperbolic from axis to axis, where for each filter the filtering is diagonal. One possible shape, 2-D Hyperbolic, is particularly advantageous in this application and has an amplitude-versus-frequency response as illustrated in Figure 3. The adjustable filter cutoff frequency generally is set to allow the GOP, the frame or the partial frame chosen to be compressed uniformly by encoder 24. If necessary, additional horizontal and vertical high frequency information may be filtered, but this is generally not needed. As the picture complexity changes, or as the available bit rate increases, the amount of data filtered by the diagonal filter and other previous filters decreases. The 2-D filter could be described, for example, as a two dimensional FIR with 13 taps in each direction (13 by 13), or as a 2-D infinite impulse response (IIR) filter.

The 2-D FIR filter included in unit 223 may be a 13 by 13 tap filter with the following tap coefficients:

20	0	0	0	1	-3	5	-5	5	-3	1	0	0	0
	0	0	1	-1	-3	9	-11	9	-3	-1	1	0	0
	0	1	-1	-4	4	6	-13	6	4	-4	-1	1	0
	1	-1	-4	1	14	-13	4	-13	14	1	-4	-1	1
	-3	-3	4	14	5	-47	61	-47	5	14	4	-3	-3
25	5	9	6	-13	-47	-55	193	-55	-47	-13	6	9	5
	-5	-11	-13	4	61	193	556	193	61	4	-13	-11	-5
	5	9	6	-13	-47	-55	193	-55	-47	-13	6	9	5
	-3	-3	4	14	5	-47	61	-47	5	14	4	-3	-3
	1	-1	-4	1	14	-13	4	-13	14	1	-4	-1	1
30	0	1	-1	-4	4	6	-13	6	4	-4	-1	1	0
	0	0	1	-1	-3	9	-11	9	-3	-1	1	0	0
	0	0	0	1	-3	5	-5	5	-3	1	0	0	0

For these coefficients, the DC gain is 1024. The coefficients exhibit octant symmetry which gives 28 independent coefficients. Symmetrical coefficient regions allows faster setup of the adjustable filter. It is possible, however, that each octant be different if, for example, an image or region being filtered exhibited different characteristic in one part of the image.

The filter response of processor 22 can vary continuously from one set of coefficients to another on a pixel to pixel basis. Thus, processor 22 may exhibit different operating parameters for maintaining good image quality under bit rate constraint, as will be discussed.

As mentioned previously, processor 22 can be adaptively modified to filter adaptively depending upon the parameter(s) used to define the filter adaptation. For example, variance in an image frame can be used to segment the image into regions for different processing. Edges are an important image feature in that dominant edges mask coding errors in their vicinity, and they can also define image regions. Colorimetry may be used to identify areas of low complexity, such as flesh and sky. Textures may be identified and processed as a region as well. Textures are generally less important than edges. Textures, therefore, identify regions which may be filtered more than other regions. Also, cinematic composition can be used to locate important figures or action which require higher coding efficiency and, thus, less filtering. Background is generally softened by the depth of field of the camera optics and may be more heavily filtered. Pan and scan information may be used to define the center of interest of an image for different processing by processor 22.

The operation of encoder 24 is compatible with the MPEG2 standard. Encoder 24 may provide information via controller 28 which processor 22 may use to enhance performance. Such information may include the bit rate information, for example. This bit rate information may comprise the average bit rate for a GOP, the frame bit rate, and the macro-block or block bit rate. Other information which may enhance the performance of processor 22 includes the discrete cosine transform complexity, the type quantization matrix being used, and the quantization matrix step size being used. Also, processor 22 may provide information to encoder 24 via controller 28 to adjust its operation to improve encoding performance.

After being formed into a transport packet data stream using known techniques, the HD signal is transmitted to a receiver in a known manner, e.g., as described in the Grand Alliance specification. Except for the required up-sampling to a full HD pixel resolution at the receiver, the signal processing provided by processor 22 is transparent to a decoder in a Grand Alliance compatible receiver.

At the receiver, the data stream is demodulated and the transport stream is processed to recover the data packets and program information using known techniques. For HD programs in the hybrid format described above, the signal is upsampled in the horizontal direction in the display processor if the display requires a full HD signal. The number of vertical lines in the image signal is unchanged. This reconstructs the full HD signal of 1920 by 1080 resolution for display by a high definition image reproducing device. If the image display device requires less than a full HD signal, the signal is appropriately down sampled during image reconstruction before display by known methods. Existing receivers which are Grand Alliance compatible require a software modification to be able to reconstruct the hybrid signal. The software modification allows horizontal and vertical hardware and software processing routines assigned

to Grand Alliance standardized modes to be independently selected as needed for the incoming signal.

Figure 4 is a flow chart of the video image signal flow through the encoding system. In step 30, the signal format is identified and the identifying information is conveyed with the video signal. The format information may indicate, for example, whether the signal is originally from a movie with a 24 frame per second format, and whether the signal is interlaced or progressive. If the video signal is interlaced, the signal is converted to a progressive signal at 60 frames per second in step 31. If the signal has been converted by 3:2 pull down, the redundant frames are removed in step 32. If the video signal is already in a camera progressive format it passes directly to the filter of step 34. In step 34, the video signal is spatially low-passed filtered. This includes vertical, horizontal and diagonal filtering as described above. Step 35 reconverts the progressive signal, which was converted from and interlaced signal in step 31, back to an interlaced signal. In step 36 the signal is subjected to 3:2 pull down to replace redundant frames previously deleted in step 32. Video signals passing directly from step 30 to step 34 above now pass directly from step 34 to step 38. In step 38, the video signal from one of steps 34, 35 and 36 is subsampled to the hybrid 1280 by 1080 HD signal resolution defined above, or to another output format as desired. In step 40, the hybrid signal is MPEG2 encoded as previously described. Step 42 transport processes the encoded signal, and step 44 modulates the transport signal as required for transmission via an output channel, such as an RF terrestrial broadcast channel. Finally, step 46 transmits the modulated signal. Steps 42 to 46 occur by known methods.

Figure 5 is a flow chart of the transmitted image signal flow through a receiver. This flow chart assumes that the image resolution of the received signal is the hybrid 1280 by 1080 HD signal defined above. In step 50, the transmitted signal is received by a tuner and demodulated. The demodulated signal is MPEG2 decoded and decompressed in step 52. Step 54 identifies the video signal resolution as 1280 by 1080 pixels per image via control information sent with the signal. The Grand Alliance MPEG2 protocol supplies image resolution information with the transmitted signal. The hybrid signal is generally identified by a unique code as is any other defined resolution. The hybrid signal could also be defined otherwise, for example, by information in the user data of the transmitted data. The hybrid video signal is horizontally upsampled to a full 1920 by 1080 HD signal during display processing in step 56. The hybrid signal is upsampled with new software in association with existing hardware and software resident in the receiver as previously described. Finally, the full HD video signal is displayed on a 1920 by 1080 display in step 58. Steps 50, 52 and 58 employ known methods.

The apparatus and methods described above can be applied in a number of configurations to achieve an improved image reconstruction for high definition display. Adaptive and non-adaptive options may be used depending on the requirements of a particular system. Some of these options are discussed below.

A non-adaptive strategy would be to set frame filtering of processor 22 to a target bit rate and allow all images to be processed uniformly. Another non-adaptive strategy would make the assumption that the center of a displayed image is the most interesting region. This also assumes that peripheries of the image are less interesting and therefore less important to the viewer. The coefficients of the filters of processor 22 are set by controller 28 via parameters which are functions of pixel spatial position and all image information is uniformly processed.

An adaptive option is to segment the image into regions using texture model parameters, local video variance, colormetrics, or other picture complexity measures based on the source image. Filtering characteristics of processor 22 are adaptively modified for different regions.

Another approach is to adaptively modify the filtering characteristics of processor 22 as a function of the difference between the actual bit rate and the target bit rate. In this case, a single parameter controls transition in filter coefficients for the 2-D frequency response.

Another strategy is to design the 2-D frequency response of the filtering provided by processor 22 to be compatible with the quantization matrix employed by encoder 24. A quantization matrix may be viewed as a low-pass filter which has 2-D shape. For this strategy the values of the filter coefficients would be a function of the quantization matrix step size. As the step size is changed according to known encoder operation, a corresponding change would occur for corresponding filter coefficients.

The options noted above illustrate the flexibility of a system employing the principles of the invention. Such a system preferably operates within the context of MPEG2 rate control to extend the MPEG2 compression capability by reducing encoding artifacts and other noise. The versatility and economics of HDTV deployment is improved through the use of the invention. The number of HD programs transmitted per transponder in a direct broadcast satellite system (i.e., 24 MHz 4-PSK) is increased from one to two programs, or one HD program with multiple SD programs. The ability to transmit one HD program with multiple SD programs in a 6 MHz terrestrial broadcast channel is attainable in accordance with the principles of the present invention. Previously, broadcasters were limited to transmitting one HD program in one channel, or multiple SD programs in one channel.

Although the invention has been described in the context of HD signal transmitting and receiving systems, the principles of the invention are applicable to other arrangements such as data storage systems. In systems such as digital video disk (DVD), video data is encoded and stored for replay at a later time. The storage medium has a limited amount of storage space available. If an encoded program, a movie, or other video sequence exceeds the amount of space available on the medium, further encoding/compression to make the program fit may create unacceptable artifacts. The invention described above may be used to efficiently encode the program to a lower bit rate allowing the program to fit on the disk. Or, multiple programs may now fit on one disk. Digital storage onto tape may also benefit as describe above.

CLAIMS

1. A method for processing first and second video signals respectively
5 exhibiting first and second dissimilar image formats, comprising the step of
detecting the presence of said first or second video signal, and further
comprising the steps of:
- A. when said first video signal is detected,
(a) converting said first video signal to a different format, to
10 produce a converted signal;
(b) filtering said converted signal to produce a filtered signal;
(c) reconvertng said filtered signal to the original format of said
first signal, to produce a reconverted signal;
(d) converting said reconverted signal to a lower resolution to
15 produce a lower resolution signal;
(e) encoding said lower resolution signal to produce an encoded
signal; and
(f) conveying said encode signal to an output channel; and
- B. when said second video signal is detected,
20 (g) filtering said second video signal to produce a filtered signal;
(h) converting said filtered signal to a lower resolution to produce
a lower resolution signal;
(i) encoding said lower resolution signal to produce an encoded
signal; and
25 (j) conveying said encode signal to an output channel.
2. The method of claim 1, wherein:
said first video signal is an interlaced scan signal, and said interlaced scan
signal is converted to a progressive scan signal in step (a).
30
3. The method of claim 1, wherein:
said first video signal is a telecined film signal, and said telecined film
signal is converted to de-telecined signal in step (a).
- 35 4. The method of claim 1, wherein:
said second video signal is a progressive scan signal.
5. The method of claim 1, wherein:
said filtering steps provide low-pass filtering.
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AMENDED SHEET

6. The method of claim 5, wherein:
said filtering steps provide two-dimensional filtering.
7. The method of claim 1, wherein:
5 said filtering steps provide adaptive filtering adjusted to one of a group of picture frames, a single frame, and a part of a frame.
8. The method of claim 1, wherein:
said filtering steps provide temporally low-pass filtering and adaptively
10 change filtering characteristics in response to characteristics of said signal.
9. The method of claim 1, wherein:
said filtering steps provide spatially low-pass filtering and adaptively
change filtering characteristics in response to characteristics of said signal.
15
10. The method of claim 1, wherein:
said encoding steps are MPEG2 compatible.
11. The method of claim 1, wherein:
20 said lower resolution signal has a resolution of 1280 by 1080 data samples per frame.
12. The method of claim 1, wherein:
said first and second video signals are high definition signals having a
25 resolution of 1920 by 1080 data samples per frame.
13. A method for processing one of an interlaced scan video signal and
a telecined film format signal, comprising the steps of:
detecting the presence of one of said interlaced scan video signal and said
30 telecined film signal,
converting said detected signal to one of a progressive scan signal and a
de-telecined signal, respectively, to produce a converted signal;
filtering said converted signal to produce a filtered signal;
reconverting said filtered signal to one of an interlaced scan signal and a
35 telecined signal, respectively, to produce a reconverted signal;
converting said reconverted signal to a lower resolution to produce a lower
resolution signal;
encoding said lower resolution signal to produce an encoded signal; and
conveying said encoded signal to an output channel.
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AMENDED SHEET

ART 34 Amdt

14. The method of claim 13, wherein:

said filtering step is low-pass filtering, and said encoding step is MPEG2 encoding.

5 15. The method of claim 13, wherein:

said lower resolution signal has a resolution of 1280 by 1080 data samples per frame.

10 16. A method for processing a non-telecined progressive scan video signal, comprising the steps of

adaptively filtering said detected signal to produce a filtered signal;

converting said filtered signal to a lower resolution to produce a lower resolution signal;

MPEG encoding said lower resolution signal to produce an encoded signal;

15 and

conveying said encoded signal to an output channel.

17. The method of claim 16, wherein:

20 said filtering step is low-pass filtering, and said encoding step is MPEG2 encoding.

18. A method for processing a non-telecined progressive scan video signal, comprising the steps of

filtering said detected signal to produce a filtered signal;

25 converting said filtered signal to a lower resolution to produce a lower resolution signal having a resolution of 1280 x 1080 samples per frame;

encoding said lower resolution signal to produce an encoded signal; and

conveying said encoded signal to an output channel.

30 19. In a high definition video signal processing system, a method for processing a received digital video signal subject to exhibiting more than one image resolution, including a resolution of 1280 by 1080 data samples per frame, comprising the steps:

decoding said signal to produce a decoded signal;

35 determining the image resolution of said decoded signal;

AMENDED SHEET

ART 34 AM

17
converting horizontal information from said decoded signal to a different resolution if said decoded signal has a horizontal image resolution of 1280 samples per line, to produce a converted signal; and
conveying said converted signal to an output device.

5

20. The method of claim 19, wherein:
said conversion is up-conversion, and said different resolution is 1920 horizontal samples per line.

10

21. The method of claim 19 wherein:
said conversion is down-conversion, and said different resolution is a lower resolution.

15

22. The method of claim 19, wherein:
said received digital video signal is MPEG2 compatible.

20

23. A method according to claim 16, wherein
said adaptive filtering is independent of signal subsampling by said converting step.

25

24. A method according to claim 16, wherein
said adaptive filtering is a function of image signal parameters prior to filtering.

30

25. A method according to claim 16, wherein
said method including said adaptive filtering step through said conveying step operates with respect to a fixed image frame format.

26. A method according to claim 16, wherein
said adaptive filtering is adaptive within an image frame.

27. A method according to claim 26, wherein
said adaptive filtering is performed on a pixel-by-pixel basis.

35

28. A signal format for conveying video information, said format being defined by 1280 picture elements by 1080 picture elements.

40

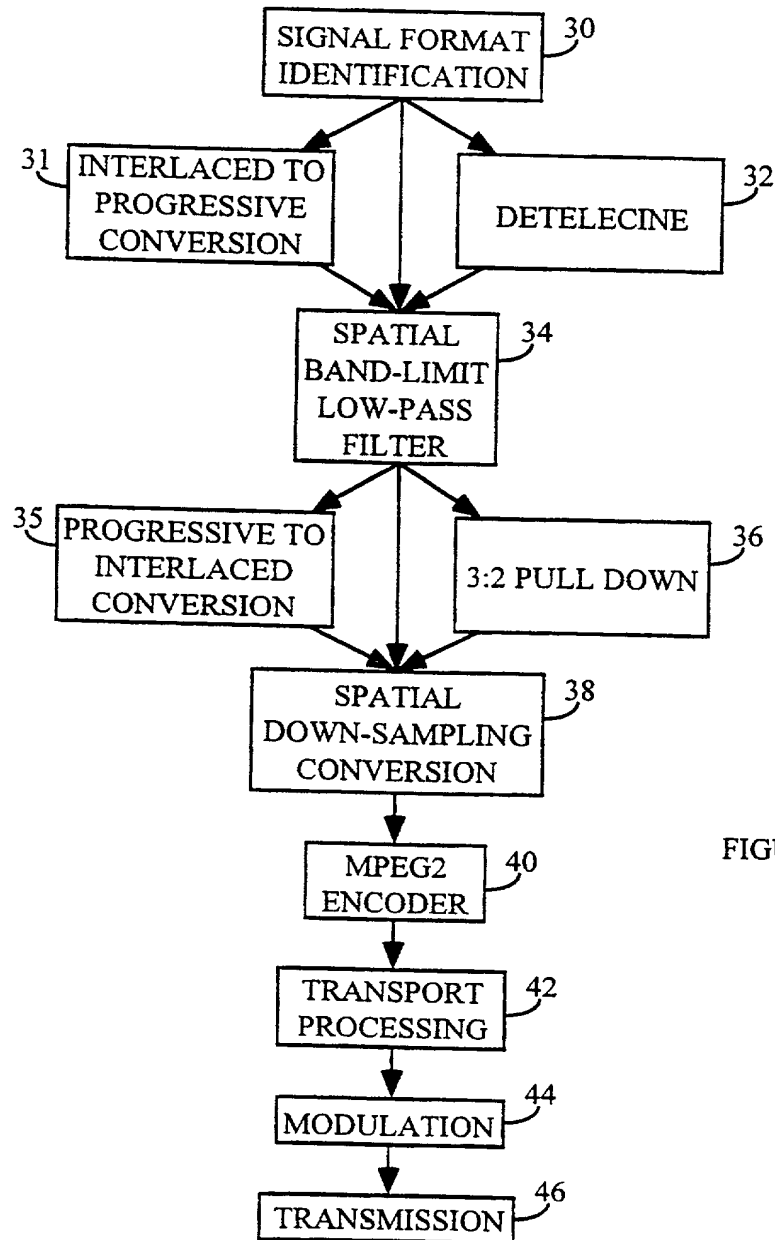
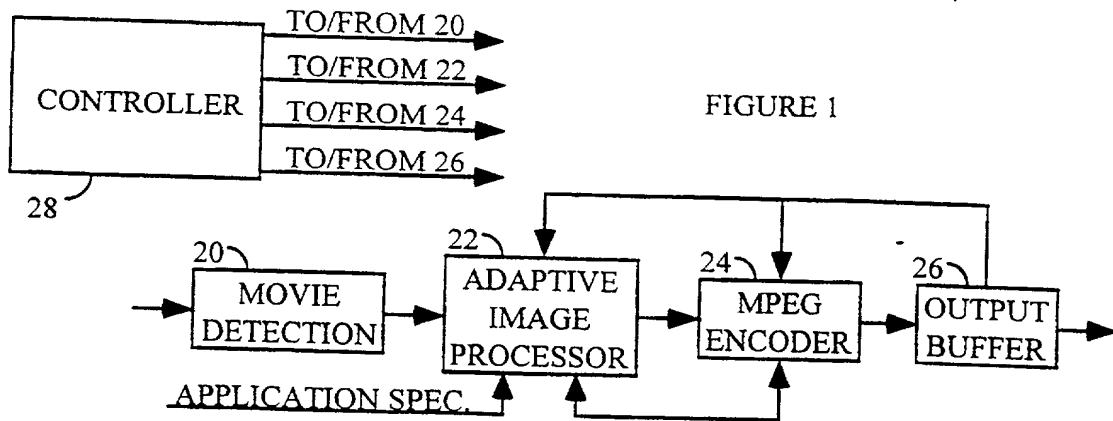
29. A signal format according to claim 28, wherein
said 1280 picture elements represent horizontal information, and
said 1080 picture elements represent vertical information.

AMENDED SHEET

18 ART 34 AMDT

30. A signal format according to claim 28, wherein
said video information is broadcast satellite information.

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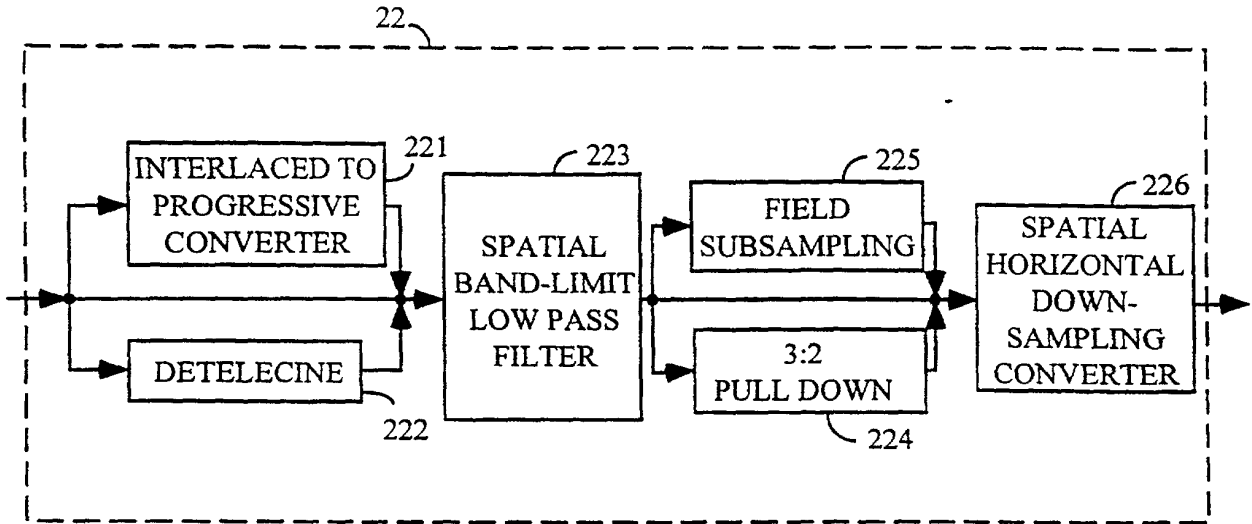
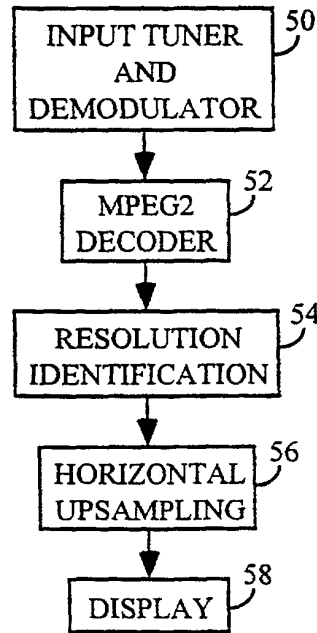


FIGURE 2

FIGURE 5



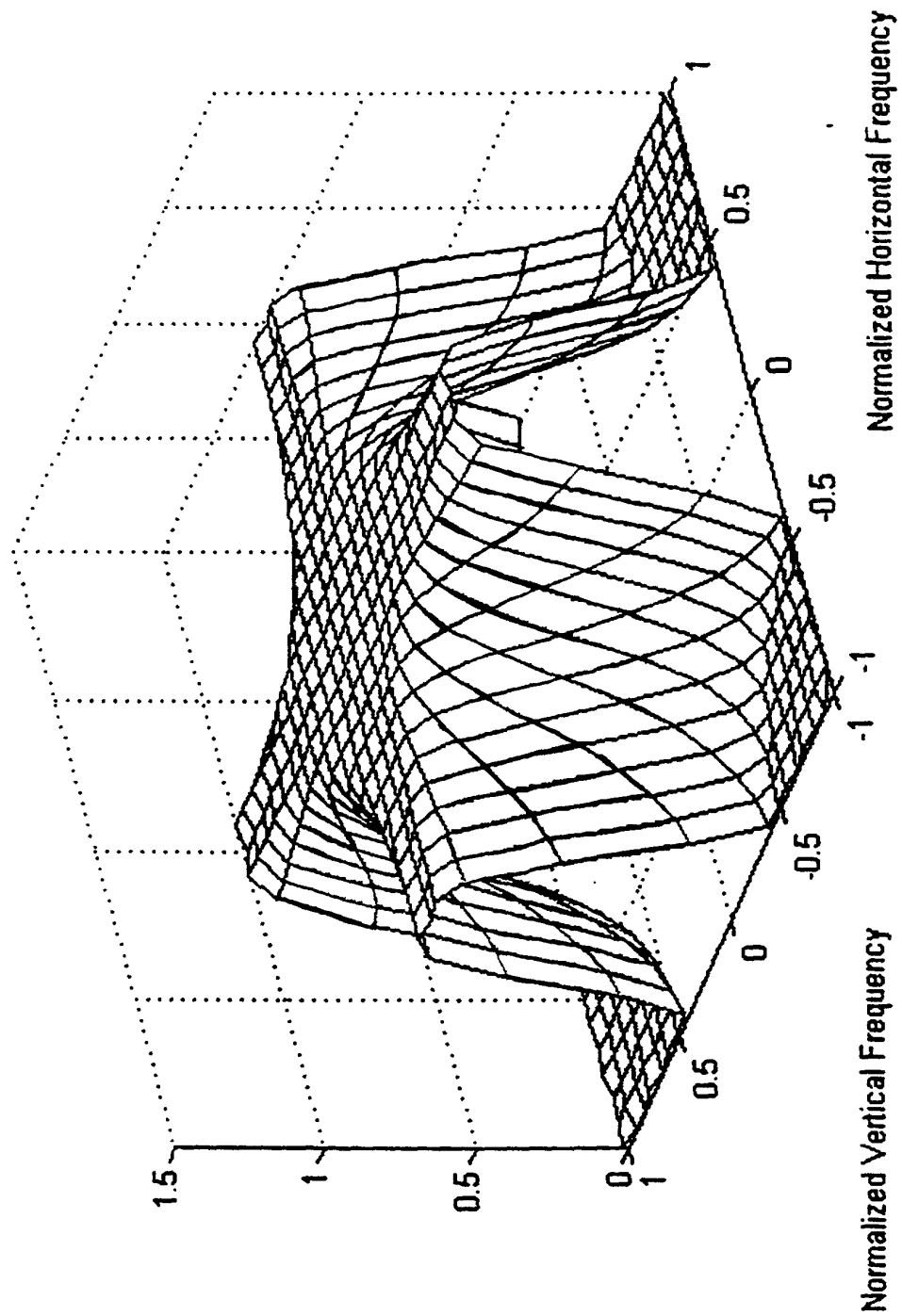


FIGURE 3

Combined Declaration For Patent Application and Power of Attorney (Continued)

(Includes Reference to PCT International Applications)

ATTORNEY'S DOCKET NUMBER
RCA 88692

416 Rec'd PCT/PTO 31 MAY 2000

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) or PCT international application(s) designating the United States of America that is/are listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in that/those prior application(s) in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56(a) which occurred between the filing date of the prior application(s) and the national or PCT international filing date of this application:

PRIOR U.S. APPLICATIONS OR PCT INTERNATIONAL APPLICATIONS DESIGNATING THE U.S. FOR BENEFIT UNDER 35 U.S.C. 120:

U.S. APPLICATIONS		STATUS (Check one)		
U.S. APPLICATION NUMBER	U.S. FILING DATE	PATENTED	PENDING	ABANDONED
PCT APPLICATIONS DESIGNATING THE U.S.				
PCT APPLICATION NO	PCT FILING DATE	U.S. SERIAL NUMBERS ASSIGNED (if any)		
PCT/US97/23992	23December1997(23.12.97)			

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. (List name and registration number)

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

SIGNATURE OF INVENTOR 201	SIGNATURE OF INVENTOR 202	SIGNATURE OF INVENTOR 203
Haoping Yu	David Lowell McNeely	Billy Wesley Beyers Jr.
DATE	DATE	DATE
May 1, 2000	27 April 2000	5/1/2000

COMBINED DECLARATION FOR PATENT APPLICATION AND POWER OF ATTORNEY

(Includes Reference to PCT International Applications)

ATTORNEY'S DOCKET NUMBER

RCA 88692

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

LOW NOISE ENCODING AND DECODING METHOD ✓

the specification of which (check only one item below):

☐ is attached hereto.

☐ was filed as United States application

Serial No. _____

on _____,

and was amended

on _____ (if applicable).

☒ was filed as PCT international application

Number PCT/US97/23992 ✓

on 23 December 1997 ✓,

and was amended under PCT Article ~~39~~ 34

on 8 July 1999 and 11 January 2000 (if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, §1.56(a).

I hereby claim foreign priority benefits under Title 35, United States Code, §119 of any foreign application(s) for patent or inventor's certificate or of any PCT international application(s) designating at least one country other than the United States of America listed below and have also identified below any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) of which priority is claimed:

PRIOR FOREIGN/PCT APPLICATION(S) AND ANY PRIORITY CLAIMS UNDER 35 U.S.C. 119:

COUNTRY (if PCT, indicate "PCT")	APPLICATION NUMBER	DATE OF FILING (day, month, year)	PRIORITY CLAIMED UNDER 35 USC 119
			<input type="checkbox"/> YES <input type="checkbox"/> NO
			<input type="checkbox"/> YES <input type="checkbox"/> NO
			<input type="checkbox"/> YES <input type="checkbox"/> NO
			<input type="checkbox"/> YES <input type="checkbox"/> NO
			<input type="checkbox"/> YES <input type="checkbox"/> NO